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ORIGINAL ARTICLES

THE FUNDAMENTAL PRINCIPLES INVOLVED IN THE USE OF THE BONE GRAFT IN SURGERY.[1]

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CELLULAR life may be quite independent of organic or somatic life, and under favorable conditions tissue cells may retain their viability long after being detached from the living organism. The duration of this cellular life depends largely upon the means of preservation of the detached parts, or, in the case of organic death, the preservation of the whole cadaver, and also the amount of disintegration from the cause of death. It is on account of this phenomenon that detached portions of living tissue can be successfully transplanted. The higher the specialization of the cell the less marked are its resisting and proliferating powers. This is especially well illustrated in the case of tissue grafts. The lower order of tissues, which need less nutrition, continue to live for days on their own substance which is contained in the serum that permeates them; but the more highly specialized ones are liable to necrose in a short time unless nourished by a blood circulation.

The most favorable tissues for grafting purposes are the simpler connective tissues, such as bone, fat, fascia, etc. Muscles and nerves are most unfavorable. Autogenous grafts, or those derived from the same individual into which they are engrafted, are by far the most trustworthy. The fluids and tissues of every individual vary in degree from those of every other, and while this incompatibility may be slight, it is sufficient cause for using, whenever feasible, the individual's own tissue for the repair of his defects.

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[1] The Mütter Lecture, delivered before the College of Physicians of Philadelphia, December 4, 1914.

With primary union and in the absence of infection, autogenous bone grafts, properly contacted, are always successful, and even infection does not necessarily indicate failure. The exact knowledge of the histological role which the bone graft plays is fortunately immaterial to its clinical usefulness, whether it serves as an osteoconductive scaffold or as an active osteogenetic force. The extensive experiments and histological studies of Ollier, Macewen, Frangenheim, Cotton and Loder, McWilliams, Phemister, and the author have proved the viability and osteogenesis of the grafts when inserted by the proper technique.

Homoplastic grafts are those which are derived from another individual of the same species, and when composed of the lower order of tissues, such as bone or facia, they may be employed successfully, but not with the same certainty as autogenous grafts; when they consist of the more highly specialized tissues, they result in failures. Homoplastic grafts are often difficult to obtain, and there always exists the danger of transmitting disease from the donor to the host even when the greatest care has been exercised.

Heteroplastic grafts are those which are obtained from an individual of another species. Living grafts from different species usually die when implanted into man or the higher animals. The graft in these cases acts more as a foreign body, and if there is infection it is liable to slough out immediately. In the event of no infection it either becomes encapsulated or disappears, and is slowly substituted by the proliferation and migration of the tissues in which it is embedded. This process may require months in the case of the bone graft, and thus it follows that the graft may be a success clinically, though histologically it undergoes partial or even complete absorption, or, in other words, it acts as an osteoconductive scaffold.

There are certain fundamental rules which should always be observed in the transplantation of all tissues. These rules must be adhered to as closely in the animal as in the vegetable kingdom. The science of grafting in the plant kingdom is centuries old. The most important rule of the process of grafting in the vegetable kingdom is the contacting of the alburnum of the scion or graft (which in a way corresponds to the periosteum) to the alburnum of the stock, or the part grafted. The contacting of the corresponding histological layers is not so paramount in the grafting of bone as it is in vegetable life, but the importance of its observance is unquestionable.

The more closely these rules are adhered to the greater will be the percentage of clinical successes. In the case of the bone transplant, nature is confronted with the following problems: (1) the rapid establishment of cellular nutrition and blood supply, which is brought about by the extension of bloodvessels, by the cellular assimilation of the serum in which the graft is immersed; (2) the union of the graft to the contacted bones or fragments of bones by osteogenesis on the part of the graft or the recipient bone, or both; (3) the adaptation in form and increased strength of the graft to its mechanical requirements through the influence of Wolff's law. If nature is to succeed in accomplishing these problems it is quite essential that both the graft and the recipient bone should be favorable to cellular life and proliferation. The surgeon can do much to aid nature by minimizing the trauma to all the tissues involved, by avoiding cellular death through either bruising or comminuting with hand tools, or by frictional heat from motor-driven instruments; by the avoidance of traumatism, thus guarding against necrosis of portions of the graft and lessening the danger of wound infection; by the proper protection and preservation of the graft bed and the graft itself from drying and possible infection; by wisely arranging his skin incision so that it will not come directly over a superficially placed transplant, as this lessens the danger of necrosis and infection; by excising, if possible, extensive scars from the field of operation, as their poor blood supply is likely to interfere with the establishment of nutrition to the graft; by closely fitting and contacting bone surfaces, which should, whenever possible, include the accurate coaptation of periosteum of graft to periosteum of recipient bone, cortex to cortex, endosteum to endosteum, and marrow to marrow; by properly suturing muscle origins and insertions to the proper mechanical locations on grafts which replace skeletal bones or portions of them (this is important if muscle control is to be reëstablished); by securing sufficient hemostasis in the graft bed, with repeated applications of hot saline solutions, and by careful tying of bloodvessels (a hemostoma not only favors the development of infection but also interferes with the early nutrition of the transplant by the permeating serum; a small amount of blood clot, however, is desirable); by including in the graft the periosteum, endosteum, and marrow, which not only contain active osteogenetic elements, but on account of their loose structure are more favorable than compact bone to a rapid reëstablishment of the blood supply with the recipient tissues of the graft bed, from whence nourishment rapidly reaches the compact part of the graft through the numerous bloodvessels passing from these enveloping membranes into the compact bone. In other words a bone graft consisting of all its elements approaches more closely a complete physiological unit, which is obviously an advantage.

Stöhr states in his text-book on *Histology:* "The bloodvessels of the bone, the marrow, and the periosteum are in the closest connection with one another and also with the surrounding structures. Small branches (not capillaries) of the numerous arteries and veins of the periosteum enter the Haversian and Volkman's canals which on the inner surface of the bone are in communication with the bloodvessels of the marrow. The latter is supplied by the nutrient artery, which on its way through the compact substance gives off branches to the same, and in the marrow brakes up into a rich vascular network."

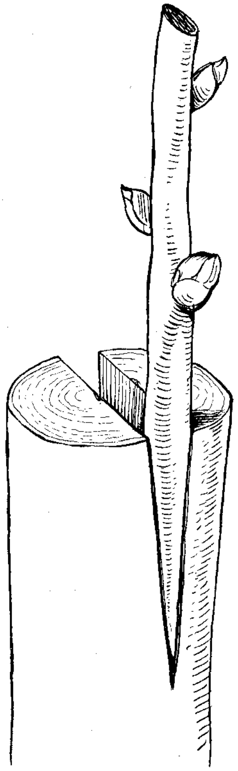

FIG. 1.—A diagram illustrating the method used most frequently in grafting fruit trees. It will be noted that it is an inlay graft and that the three elements of the graft or scion (namely, the bark, alburnum (sap) and wood) are closely coapted with their corresponding elements of the stock or recipient branch. This contact of individual tissue layers is most essential in tree grafting, and it is believed to be analogous to bone or other animal tissue grafting.

The bone contact should be of generous extent, and always to healthy vascular osteogenetic bone—the more unfavorable the bone the greater should be the area of contact. Careful suturing as well as accurate coaptation should be secured, when early use is to be made of the part, in order to obtain the benefits of functional irritation. In many instances early bony union may be enhanced by the interposition of numerous small grafts or fragments of bone. These coalesce with each other, and also with graft and recipient bone.

The ideal contact of these bone elements can only be secured by the employment of the inlay principle of procedure, which should always be carried out as carefully as circumstances permit. Examples of the various modifications of this principle are the inlay spinal graft for Pott's disease, the bone graft wedge for the correction of deformities, and the inlay for fresh and ununited fractures.

Bone grafts have been successfully applied by other methods, but the following are some of the obvious advantages of the inlay method besides the approximation of corresponding bone elements of graft to recipient bone which this procedure makes possible. Its modifications meet practically all mechanical requirements; it is as applicable to fracture of the small bones of the forearm as of the tibia or femur; it controls the deformity of the foot as well as of spinal caries. Its inherent mechanics favor the fixation of the graft as well as the immobilization of the fragments into which it is inserted. Its technique is not difficult because it has to do with plane surfaces.

A thorough understanding of the *modus operandi* and theory of Wolff's law is imperative. The influence of this law upon the success of bone-grafting procedures of all kinds cannot be too strongly emphasized. It not only influences the graft to proliferate and strengthen to an almost unlimited degree, if the new mechanical environment of the graft requires it, but this law also causes the bone from which the graft was removed to be restored to its original strength. This same influence also causes internal reconstruction of not only the trabeculæ as the mechanical forces demand, but also of the general histological character of the bone, *i. e.*, cortical bone ultimately becomes spongy bone if implanted in or contacted with bone of that character, and *vice versa*.

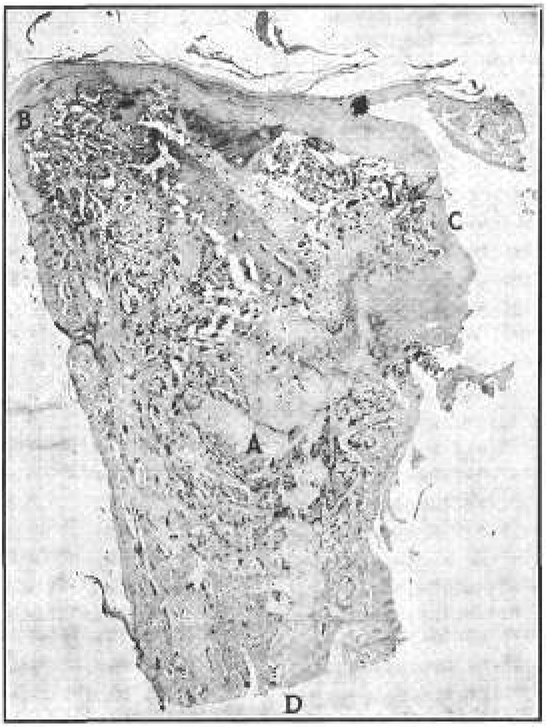

FIG. 2.—Photomicrograph of section through the long axis of spinuous process of a dog with a cross-section of an autogenous ulnar graft (*A*, *B*, *C*) thoroughly united by new bone two months after the graft was inlaid into the split tips of three spinous processes. The analogy to the technique of the tree graft (Fig. 1) is apparent. A careful microscopic study of this section has failed to disclose dead bone cells. The corners of the graft are indicated by *A*, *B*, and *C*. *D* indicates base of spinous process. The author's surgical experience in over 250 cases, as well as a large amount of animal experimental work, has convinced him that the inlay method of insertion affords by all means the most favorable graft environment, as this and many other microscopic sections have proved.

A brief statement of Wolff's law is as follows: "Every change in the form and position of the bones, or of their function, is followed by certain definite changes in their internal architecture, and by equally definite secondary alterations of their external conformation, in accordance with mechanical laws."

The external shape of the bone is the result of functional adaptation. The bone is strengthened and thickened at those points where most stress and pressure come upon it, and is weakened at the opposite points. Such transformations have the object of enabling the bones or grafts in their altered positions and relationships to meet the new and abnormally directed stress thrown upon them.

Local or general hypertrophy of a graft may occur.

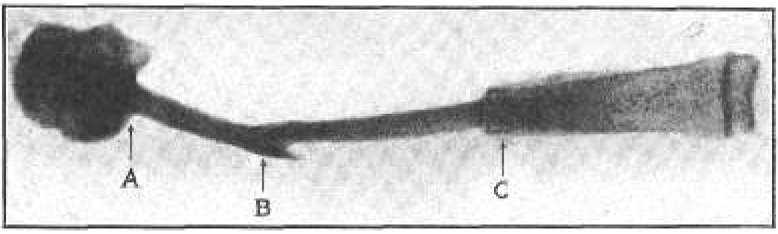

FIG. 3.—Skiagram of two grafts, each three inches long, inserted by the author for a tibial defect from the removal of two-thirds of its shaft for sarcoma. It was necessary to amputate the leg just four weeks after the insertion of the grafts, on account of the recurrence of the sarcoma, and in this short time the grafts had become firmly united (at *C*) by solid bone, although the diameters of the grafts both above and below the union remained the same as when implanted. These proliferating callus bone cells could have originated from no other source than the two graft ends, thus proving conclusively the active osteogenesis of these free grafts. The efficiency of the bone graft could not be better demonstrated than by this specimen. *A*, indicates where firm union has occurred between the upper graft and the upper remaining end of the tibia; *B*, where the lower graft has become united to the lower fragment of the tibia; *C*, indicates firm bony union between the two graft ends which were contacted in the centre of the leg far away from any possible source of new bone.

Local hypertrophies may occur in consequence of increased strain upon certain parts of a graft, either directly or through muscle pull.

Recognition and full appreciation of these important conclusions of Wolff constitute the foundation of the treatment of deformities and the application of grafts of all kinds. It is obvious that it is always advisable to allow the graft to functionate as early as possible by bearing mechanical stress within the limits of safety. This is highly favorable to osteogenesis, establishment of blood supply, and bony union. This functionating period should be preceded by the most efficient fixation of the parts grafted for an interval of not less than five weeks.

Although not advisable, many liberties can be taken with the bone graft without interfering with its success. It has certain bacteria-resisting properties.

The author's experimental grafts were kept in normal salt solution for varying periods up to one week, with successful results following their implantation. In other cases, sepsis occurred immediately after insertion of the graft (experimental); nevertheless, parts of the grafts became united to recipient bone, while the rest of the implant sequestrated.

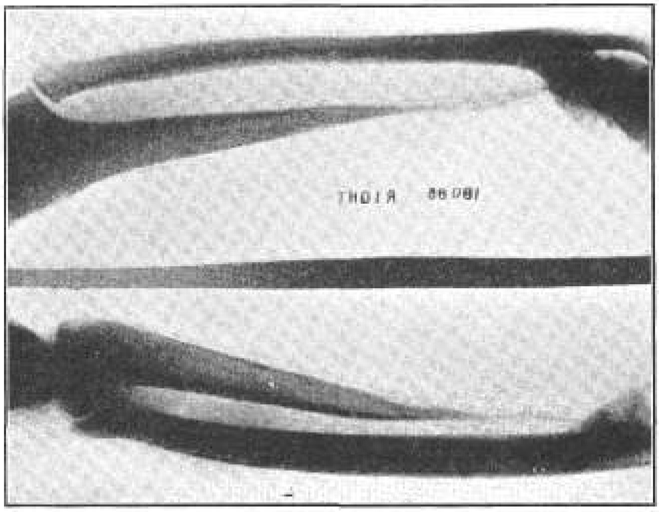

FIG. 4.—This is a skiagram of a case of loss of the lower one-third of the tibia one year before from osteomyelitis. The remaining periosteum attempted to reform the shaft and a small interrupted thread of bone can be seen. It, however, either became broken in two places or a complete bridge of bone was never produced; therefore, the influence of Wolff's law did not operate to stimulate bone proliferation as it would have if there had not been a solution of continuity. The potency of this same Wolff's law, however, could not be better demonstrated than it is in this same skiagram, as shown by the enormous hypertrophy of the fibula, which has become the size and strength of a normal tibia. This is a physiological property of bone, and shows itself as strikingly in bone grafts under functional stress as it does in complete skeletal bones. Therefore, as stated elsewhere, at the same time the graft is proliferating, in order to be of sufficient strength for its new environment, the tibia from which it was removed proliferates under the stimulus of function until it has returned to its normal strength and size.

Human autogenous grafts have been repeatedly so placed that they extended through, at their middle portion, tubercular foci, and in no case has primary union or taking of the graft failed. Likewise grafts have been so placed as to span attenuated pyogenic infected areas, and here the grafts have been equally successful.

Experimental grafts taken from long bones, such as the tibia or ulna, showed evidence of greater osteogenesis than those taken from vertebral spinous processes. Bone from which the periosteum had been removed proved equally satisfactory to bone grafts on which the periosteum had been retained.

It is deemed advisable, as stated elsewhere, to always include the periosteum, endosteum, and marrow substance, when possible, on the graft.

The bone graft acts always as a stimulus to osteogenesis to the bone into which it is engrafted or to which it is contacted. This is a constant and important factor, and may be depended upon toward securing results. If the graft is placed in a location where there is no mechanical function for it to perform its cells retain their vitality, but nearly always there will be few or no proliferative changes in the transplant. On the other hand, if it is transplanted into a defect where there is a demand for it to perform a mechanical function, proliferative changes are usually marked, and it rapidly becomes united and similar in structure to the part to which it is

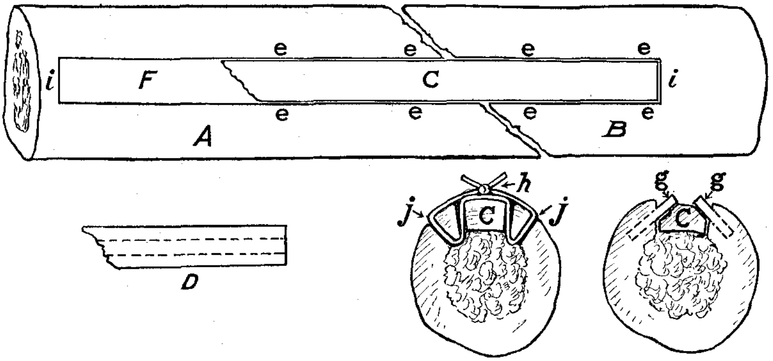

FIG. 5.—Diagram illustrating the author's application of a sliding-inlay-graft to an oblique fracture of a long bone as a substitute for a Lane's plate. The inlay should always be inserted, when possible, on the side of an oblique fracture, as indicated in this drawing. Over-riding of fragments and shortening of the limb are thus prevented by virtue of the mechanical property of the inlay, with the author's twin-circular motor saw adjusted, as to distance apart, according to the diameter of the bone. Parallel cuts to the marrow cavity are made extending into the upper or, if necessary, the long fragment (*A*) for a distance varying from four to six inches. The cuts are then extended into the lower fragment (*B*) one-half the distance, or two to three inches. These strips of bone are cut off at *i* with a small circular saw. The short strip of bone *D* from the lower fragment is then removed, producing a cortical gutter, and the longer strip *C* from the upper fragment is reversed ends and slid into the gutter in the lower fragment. It then remains to choose between heavy kangaroo tendon or bone dowel pegs to hold the inlay in place and thus immobilize the fracture-fragments. *D* is cut longitudinally along the dotted lines with a motor saw into two or three fragments, which are pushed through the author's motor-surgical-lathe and turned into perfectly round dowels each two to three inches long. These are cut with a motor saw into short pegs (*g*) and are placed in drill holes over the graft as indicated at *g* and *e*. These holes are made with a motor drill which is the counter-part, in size, to the dowel cutter. Therefore the fit must be accurate. If kangaroo tendon is chosen, *h* indicates the tendon tied at that point. *j* and *e* indicate the location of the drill holes through which the tendon is passed.

grafted. This is the law of functional irritation as laid down by Roux. The more perfect the technique of transplantation the greater will be the effect of this law of irritation.

The bone graft, when well contacted, becomes immediately adherent to the recipient bone by newly formed tissue, which usually changes to solid bone within four weeks. This, in the author's opinion, together with the graft's bacteria-resisting property, strongly favors, when feasible, the employment of the bone graft in place of any metal internal splints, especially when it is appreciated that metal has an effect opposite to that of a graft in that it inhibits callous formation, produces bone absorption, and favors infection.

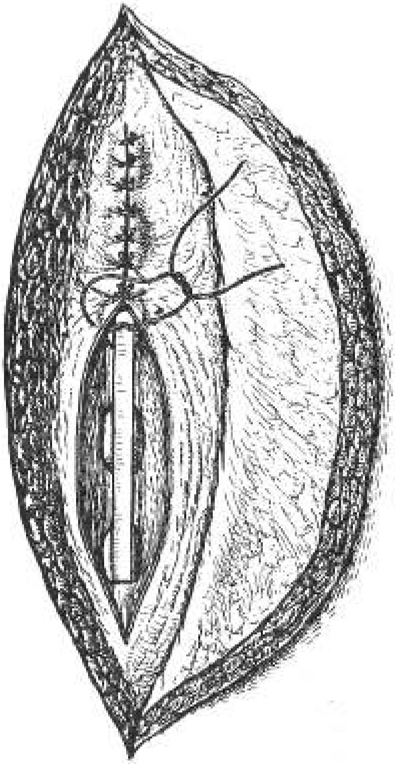

Fig. 6.—Drawing demonstrating the author's inlay bone graft inserted into five split spinous processes for vertebral tuberculosis. In the lower part of the wound the split supra- and intraspinous ligaments have been drawn over the lower end of the graft by means of heavy kangaroo tendon.

The dowel, the inlay, and the wedge bonegraft fulfil all mechanical requirements and afford a means of repairing and remodeling the skeleton which the surgeon has not hitherto possessed.

PRESERVATION OF THE BONE GRAFT. Various methods have been suggested for the preservation of bone-graft material, but in the experience of the author the following have proved most convenient and reliable.

The temporary emersion in normal salt solution is most satisfactory, and even this is not usually necessary, as, when possible, the graft bed should always be prepared prior to the removal of the graft, and the graft is immediately implanted in the prepared bed. This sequence of the operation is important, because (1) it assures an interval of time for the more perfect hemostasis in the graft bed; (2) it enables the surgeon by means of calipers and flexible sterile pattern rod to obtain the exact size and contour of the graft required, thus avoiding unnecessary traumatization from holding forceps in reshaping a graft after its removal. Even in grafts where drill holes are necessary it is far preferable to drill the graft before loosening it from the bone from which it is obtained. A graft should always be used as soon after its removal as possible, but if it is necessary for any amount of time to elapse before it can be used, normal saline solution is not satisfactory as a preserving medium because of its evaporation and the consequent toxic effect. In both experimental and human work of the author, sterile vaselin

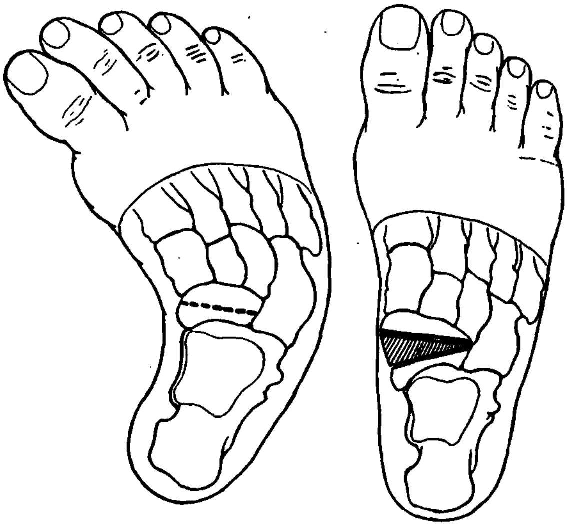

FIG. 7.—Diagram illustrating an inlay wedge bone graft removed from the crest of the tibia or the cuboid of the other side of the foot and placed into the split scaphoid for the purpose of permanently remodelling the tarsus of a congenital club-foot. In this deformity the inner side of the tarsus is shorter than its outer side, and the graft is inserted to overcome this distortion in older children and adults. The advantage of guarding against relapse by remodelling the bony tarsus is also augmented by lengthening the foot, which is always short.

has proved a most satisfactory medium in which to keep the graft. It is not only perfectly non-toxic, but it is an efficient preventive of drying. The graft should either be immersed in a jar of vaselin or wrapped in gauze smeared with the same and placed in cold storage at a temperature of 4° to 5° C. Freezing is not desirable, as the resultant contraction and expansion damages the cellular content of the graft. Human grafts removed from cadavers and from other individuals have been successfully kept by the author for forty-eight hours on ten different occasions.

Emphasis should again, however, be laid upon the importance of using autogenous bone grafts whenever possible, as they are the most reliable; and as they are always used immediately, no preserving medium is necessary.

The surgical status of the value of the bone graft has now become so thoroughly established that the surgeon should be ready and equipped to make the best use of it in every individual case requiring boneplasty, where it may be indicated. An unabridged enumeration of the indications for the employment of the bone graft would be most difficult, and the following tabulation serves only as a suggestion of its broad field of usefulness:

General Indications. 1. To immobilize and stimulate osteogenesis in certain tuberculous joints.

2. To repair traumatic bone injuries.

3. To replace bone destroyed by infection.

4. To supply bone congenitally absent.

5. To strengthen or replace bone weakened or destroyed by benign or malignant growths.

6. To correct congenital or acquired deformities of the face.

7. To establish joints congenitally absent and restore those destroyed by disease.

8. To fix in place certain dislocated joints, acquired or congenital.

9. To close bone foramina in neuralgias.

10. To correct congenital or acquired deformities of extremities of trunk.

More specific indications for the bone graft are:

1. To immobilize, support, and stimulate repair in spinal vertebræ whose bodies are infected with tuberculous or other chronic infections where mechanical treatment is indicated. It is also applicable in cases of persistent non-union following fracture of the spine, presenting pain, disability, and increasing deformity, and should be inserted as for Pott's disease. Further indications are for certain fresh fractures of the spine; spondylitis traumatica (Krummell's disease) and neuropathic spine (Charcot), where, on account of a rarefying osteitis, crushing of the vertebral bodies and increasing deformity is likely to produce cord compression.

2. In the support and immobilization of cases of tuberculosis of the sacro-iliac joint, in certain desperate cases of tuberculosis

of the tarsus, and in the form of inlays to hasten or insure bony union in erasure or excising operations for adult tuberculosis of the knee or the hip.

3. In certain cases of paralytic scoliosis to support the weakened spine and prevent lateral deviation, due to superincumbent weight and unbalanced muscle pull.

4. To immobilize and support or replace bones of the tarsus or carpus destroyed, or partly destroyed, by tuberculosis.

5. To correct deformity or restore balance in congenital club-foot and acquired deformity from local disease or paralysis.

6. As a substitute for all metal plates, screws, nails, spikes, and wires, as used in the internal fixation of fractures and other conditions. The graft is in the form of inlays and various sizes of nails or pegs, and is employed by the author in all types of fractures, such as fresh and ununited fracture of the long bones and neck of the femur.

7. To produce a permanent closure of nerve foramina after nerve resection for neuralgia (Kanavel).

8. As a prevention to luxating or slipping patellæ by raising the low femoral condyle by inserting a graft in the form of a wedge.

9. To aid, in the form of numerous small grafts, rapid bone union where joint resection has been done or where a large graft has been used.

10. To strengthen and prevent lordosis or other deformity of the spine, in cases of spina bifida, where a large amount of bone is congenitally absent.

11. To replace the head and neck of the femur, when previously destroyed by disease, the head and neck of the astragalus being used as the graft (Roberts).

12. In congenital and paralytic dislocations of the hip where the acetabulum is shallow and the femoral head will not remain in place. The upper half of the meager rim of the acetabulum is separated with a chisel and forced out and down, forming a pronounced rim. The cuneiform cavity thus produced is filled with wedge grafts.

13. To produce an ankylosis of the ankle joint in sever paralytic cases, or tuberculosis in the adult, by placing a bone-graft peg through the os calcis and into the lower end of the tibia (Lexer).

14. To replace bone removed for osteomyelitis, tuberculosis, and spina ventosa.

15. For deformities of the nose by contacting graft with nasal bones. If the skin incision is made in the tip of the nose the scar is not noticeable (Carter).

16. To replace or repair defects of the lower jaw.

17. In intra-articular fracture-dislocations the head of the humerus or femur, etc., should be replaced, at an open operation, as a graft.

SUMMARY. The bone graft is a trustworthy surgical agent, as proved by my uniform success, in its use in over 350 surgical cases. Also by a careful study microscopically, macroscopically, and by the Roentgen rays of its results, when used experimentally, both in the presence of primary union and sepsis. The cortical graft's field of usefulness is distinctly enhanced because of its resistance to tubercular and attenuated pyogenic infection.

Its field is also enlarged by the use of the author's motor-driven instruments, circular saws of different sizes, the adjustable twin saws, and the lathe or dowel instrument with different adjustments for making various sizes of bone graft inlays, nails, or spikes as they are needed.

By the use of this motor outfit and its products in conjunction with kangaroo tendon I have been able to avoid entirely the use of all metal in the form of screws, nails, Lane's plates, wire, etc., for internal bone-fixation purposes during the past two years. This has been made possible, largely, by making the best of well-known fundamental mechanical devices hitherto rarely, if at all, used in surgery, such as bone inlays, wedges, dowels, tongue and groove joints, mortised and dove-tail joints.

GASTRIC ULCER.[1]

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I HAVE thought it of sufficient interest to bring before the College certain questions relative to the treatment of gastric ulcer which have interested me very much, and which I have worked out to my own satisfaction along lines not universally endorsed perhaps by surgeons doing this work, but which I feel sure will prove to be the solution of certain vexing problems.

The experience of the last few years of activity in gastric surgery has shown both brilliant successes and dismal failures. It has shown that no one operation will fit all cases, that variations in situation, chronicity, and complications demand different methods of treatment, until finally, by the slow evolution of clinical experience and observation, we are in a position to draw some conclusions as to the principles which should underlie the surgical treatment of gastric ulcer.

Speaking of gastric ulcer in general, we must all agree that the treatment is aided by understanding both the predisposing and provocative causes which are responsible for the condition. Greater

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[1] Read before the College of Physicians, Philadelphia, January 6, 1915.